Natural Gas Pipeline Sensors

PAC Technical Meeting

Monday, April 09, 2012

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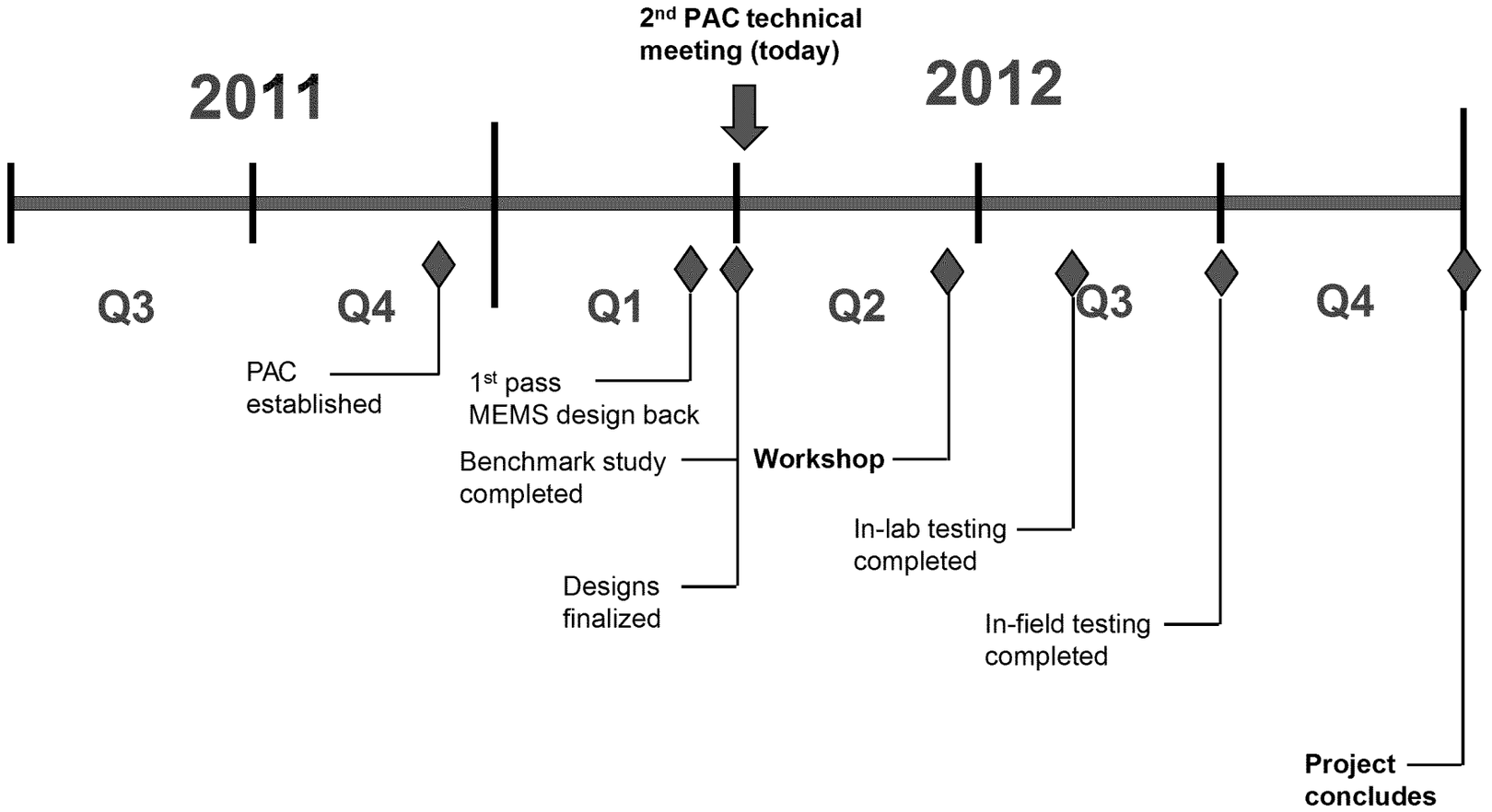
Agenda

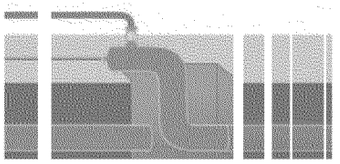
- Introduction
  - Timeline
- Benchmark Study
- Wireless Sensor Modules
- Laser Ultrasonic Testing (LUT)

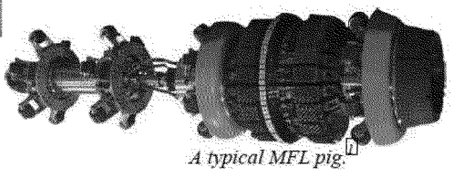
Project Timeline
UC Berkeley - Natural Gas Sensors



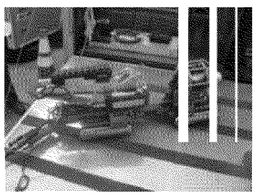
Benchmark Study

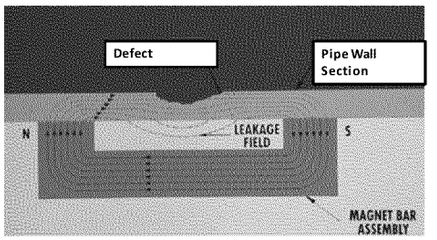
- Goal:
  - Evaluate existing diagnostic equipment against a set of metrics
- Researching existing diagnostic methods
  - Hydrostatic Pressure Testing
  - Pipeline Inspection Gauge (PIG)
  - Robotic pipe crawler
  - Magnetic Flux Leakage (MFL)
  - Eddy Current Detection (ET)

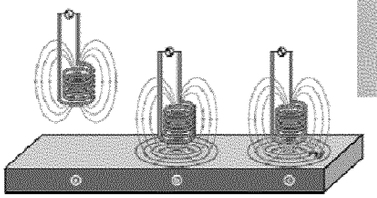




A typical MFL pig.[7]







a—The alternating current flowing through the coil at a chosen frequency generates a magnetic field around the coil.

b—When the coil is placed close to an electrically conductive material, eddy current is induced in the material.

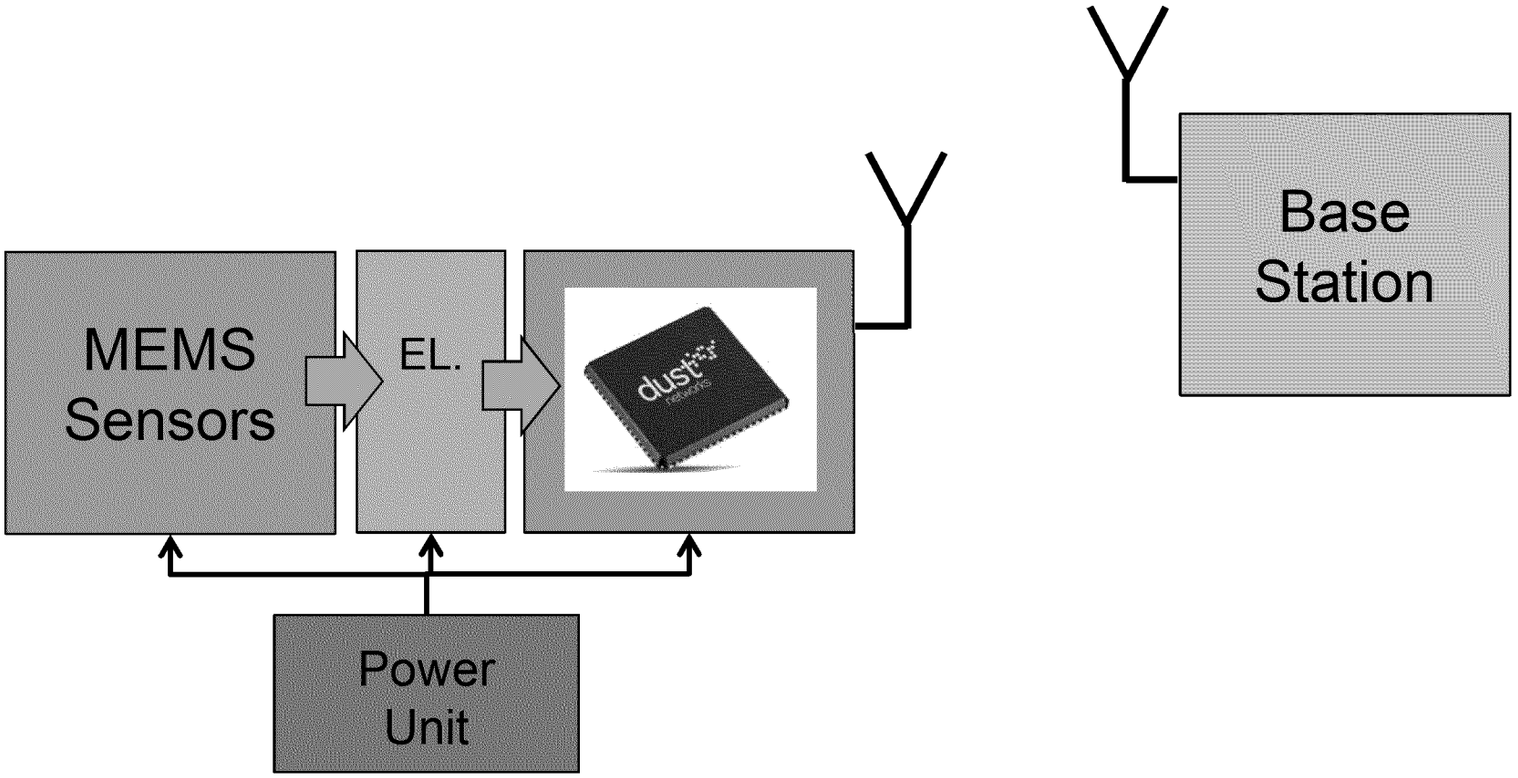
c—If a flaw in the conductive material disturbs the eddy current circulation, the magnetic coupling with the probe is changed and a defect signal can be read by measuring the coil impedance variation.

Benchmark Study (2)

- Conducted needs analysis
  - Sent out questioner, site visit, interviews
- Online sensors that would be useful

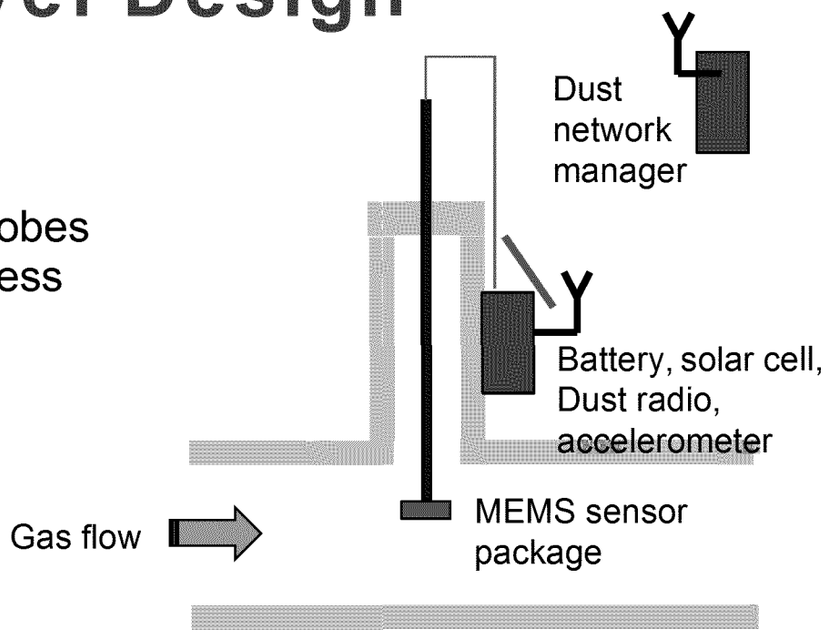
Pressure sensors (MEMS/low cost)	Fabricating
Flow sensors (MEMS/low cost)	Designs
Vibrations sensors (distributed/low cost)	Off the shelf
Moisture sensors (MEMS/low cost)	Pr. Designs
Odorant level sensors (low cost)	Pr. Designs
Methane detector (low cost)	Pr. Designs
Laser Ultrasonic's (Weld/Corrosion detection)	Designs / Collaboration

System-Level Design

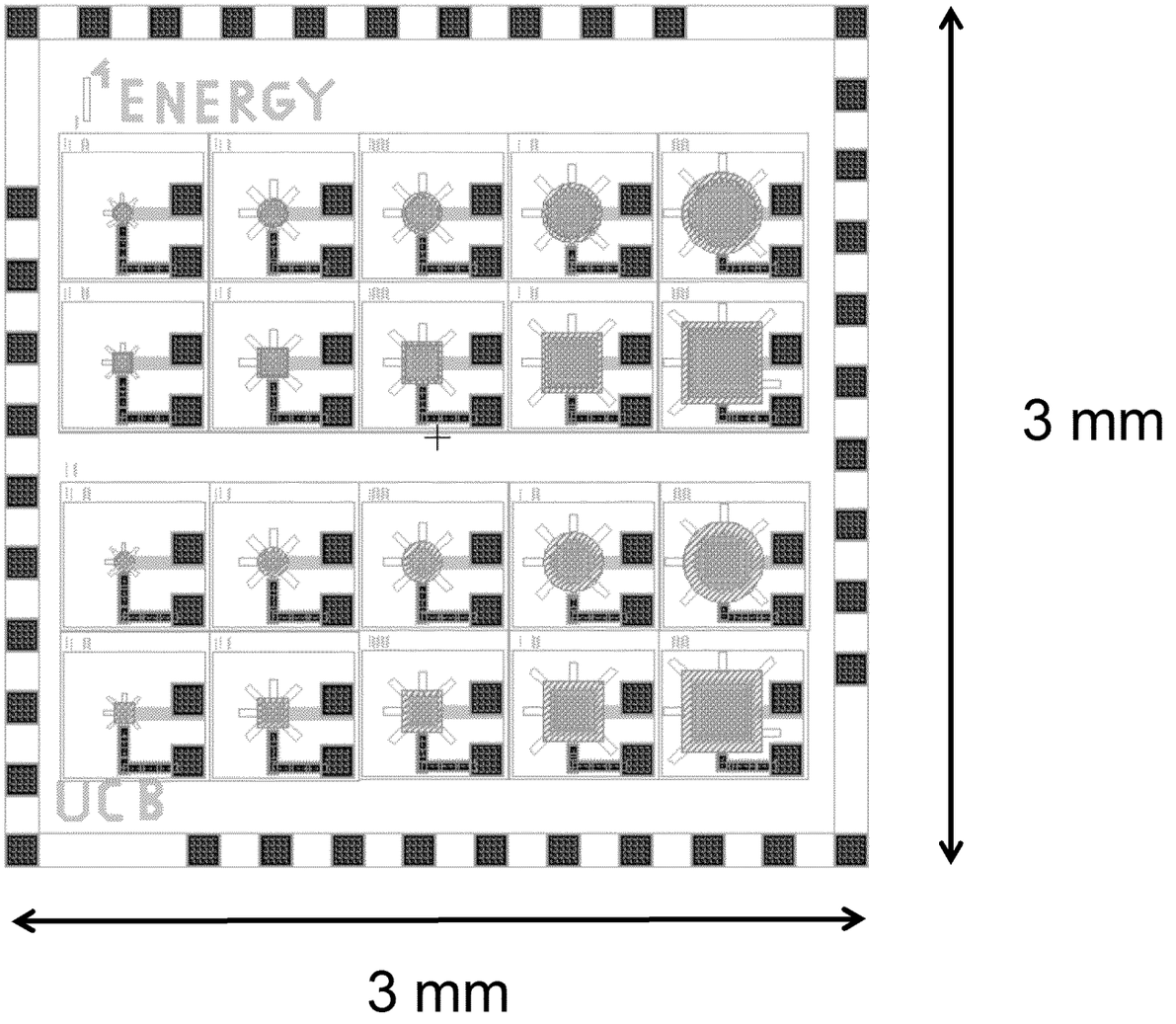


System-Level Design

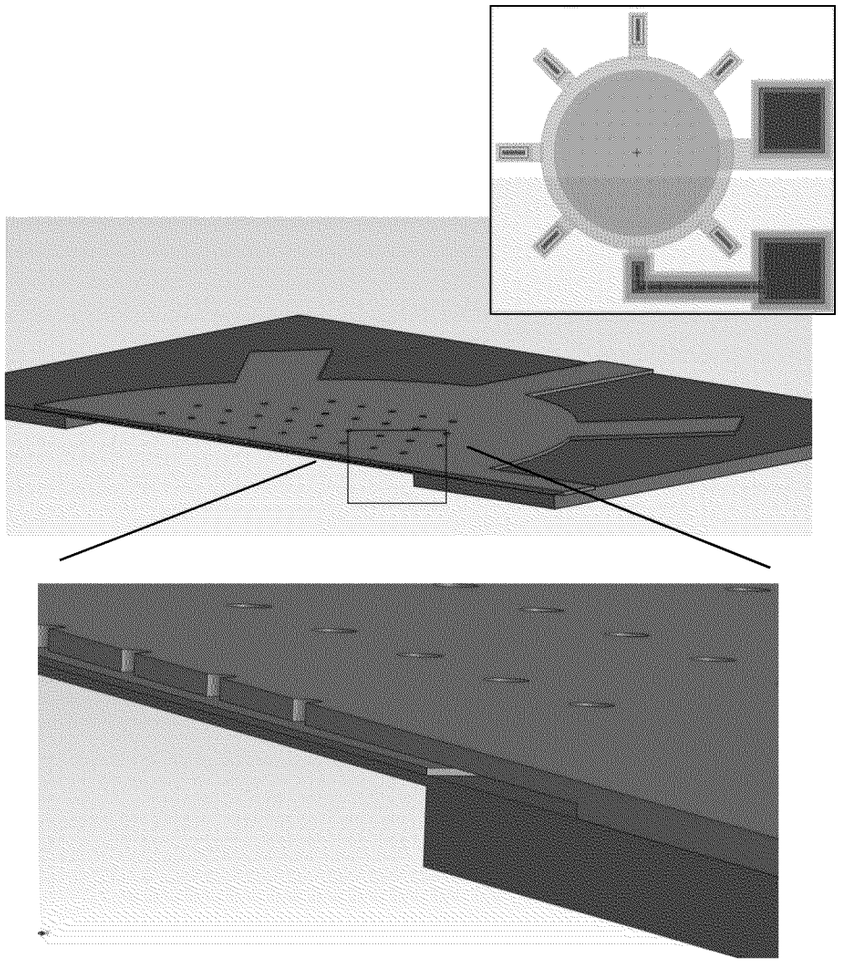
- Baseline design
  - Sensors deployed as retractable probes into the gas flow via the ¾ inch access port.
- Sensor suite
  - Pressure
  - Flow
  - Accelerometer (external)
- Radio
  - Dust Networks (~70 µW standby)
- Power
  - Battery/Solar (>10 year lifetime)

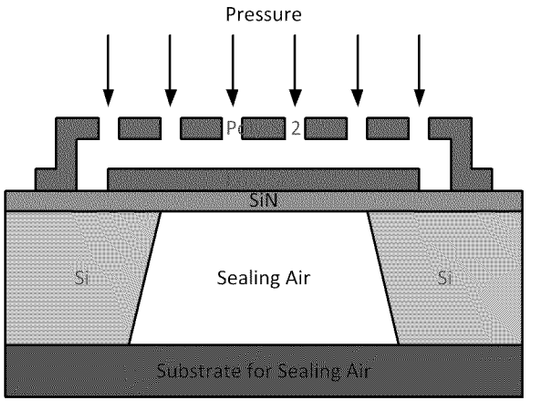


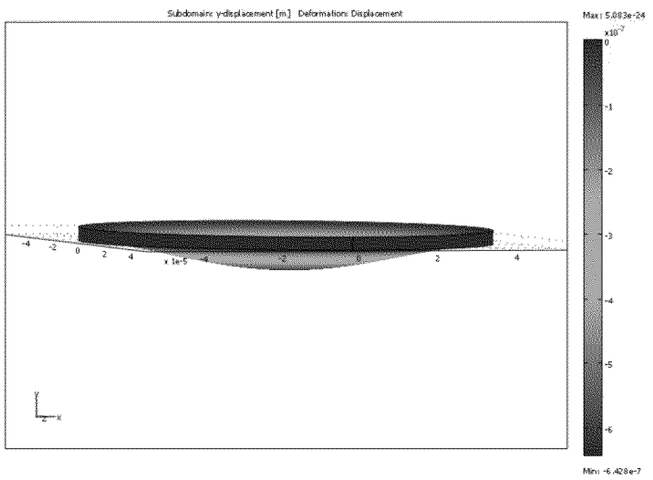
Diaphragm Based MEMS Sensors



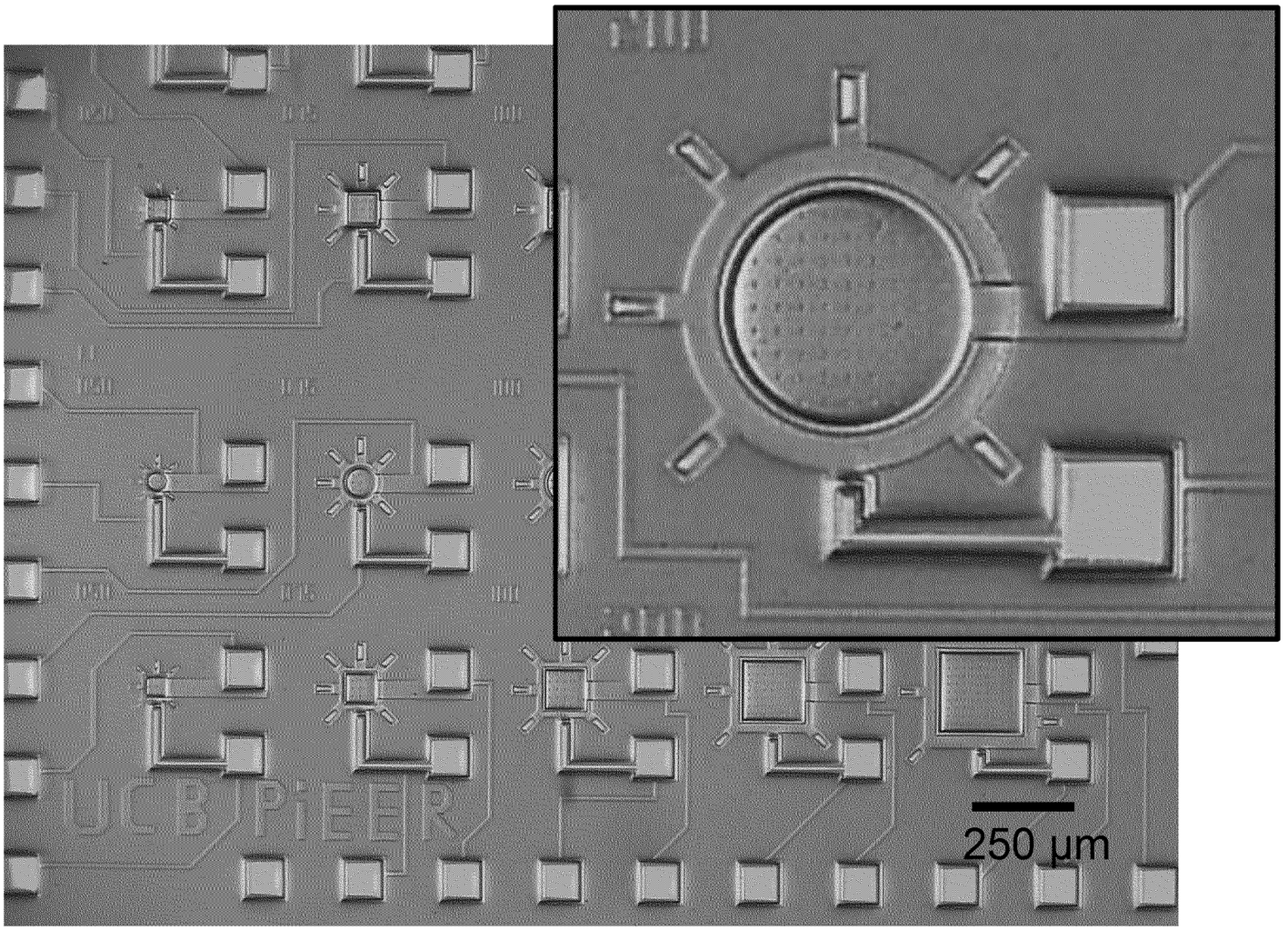
Diaphragm Based MEMS Sensors (2)



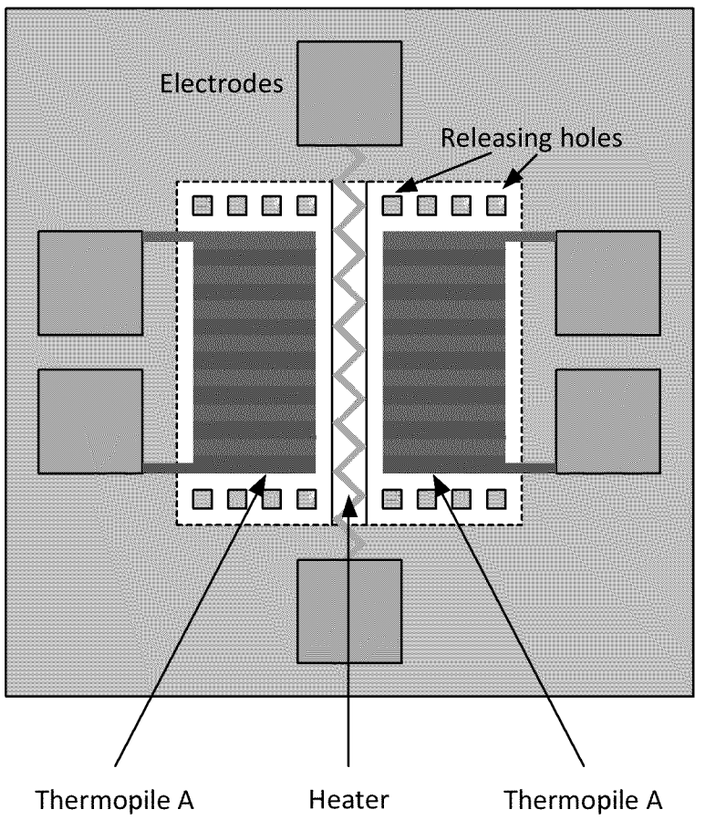


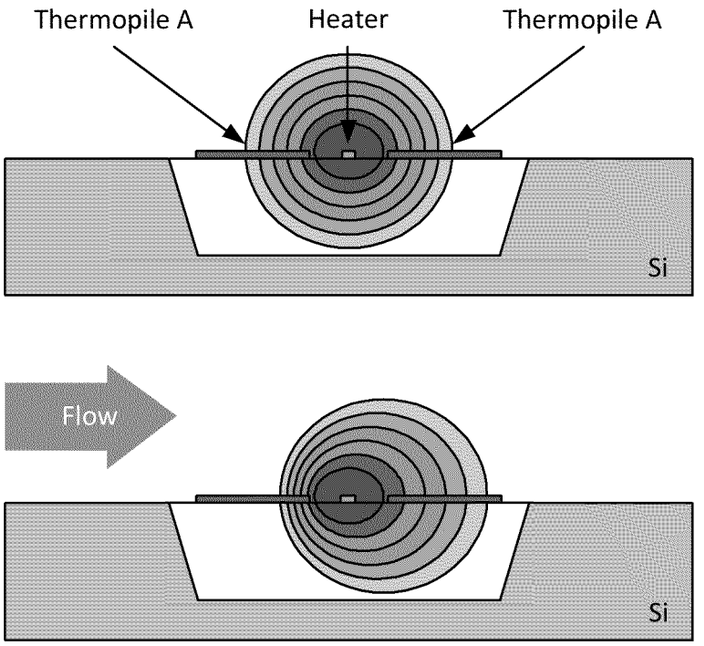


Diaphragm Based MEMS Sensors (3)



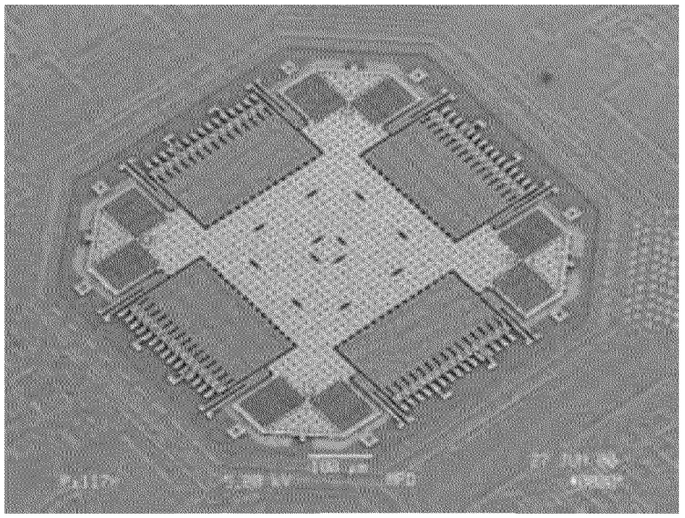
MEMS Flow Sensors



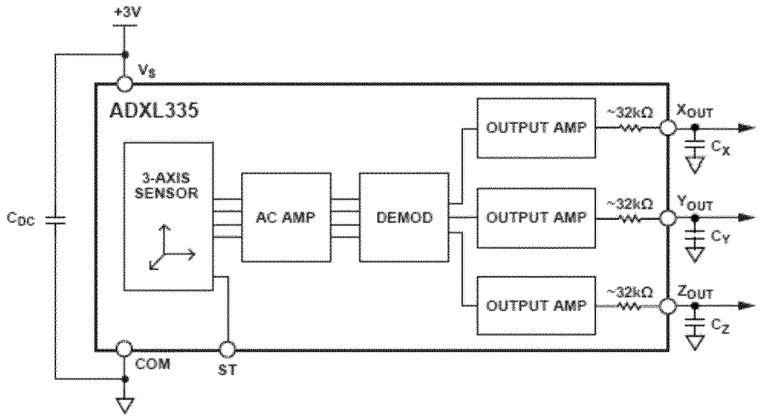


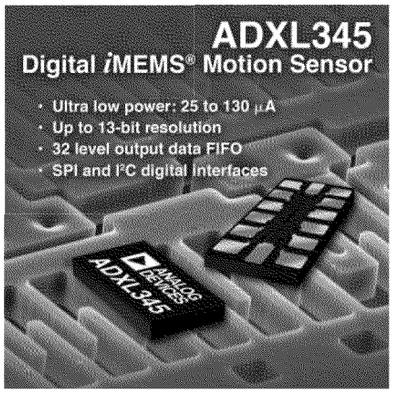
MEMS Accelerometers

- Excellent off-the-shelf accelerometers w. post-processing circuitry available from several vendors.
- Price-range in single dollars.



FUNCTIONAL BLOCK DIAGRAM





Images from Analog Devices

Prospective Sensor Concepts

- Moisture
  - Aluminum Oxide detector (ALN - large surface area)
- Odorant Level
  - Reactive membrane/resonator
- Methane
  - Reactive membrane/resonator

- Advanced Concepts
  - Self-distributing inline sensors
  - Intelligent Sensor Suite

Laser Ultrasonic Testing

- A non-destructive ultrasonic measurement technique called *Laser Ultrasonic Testing (LUT)* has been used for a few decades to do non-contracting ultrasonic detection of material properties of objects that are strongly contoured
  - bodies of jet fighter planes
  - conventional railroad rails
- Commercial vendors for LUT inspection equipment exist, including several in California.
  - Recommended that CEC consider LUT for natural gas pipeline evaluation.

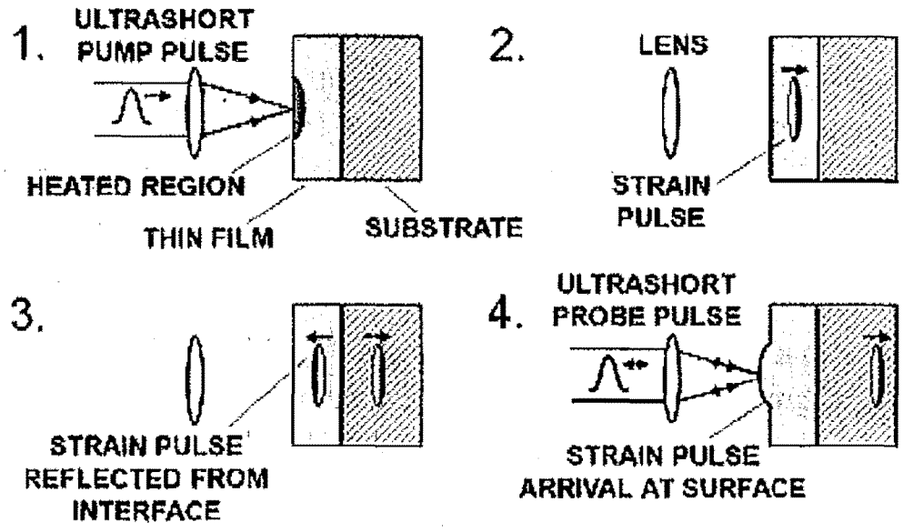
Visits to PG&E's San Ramon lab

- On 4 November 2011 we met with PG&E engineers and several of their contractors at the lab in Danville, CA where much of PG&E's work on the gas pipeline problems is being done.
  - Engineers enthusiastic about the potential of laser ultrasonic testing (LUT) to evaluate installed gas pipes.
- On 7 April 2012 we met again to discuss using their "crawlers" to carry out LUT inside pipes

What is laser ultrasonic testing (LUT)?

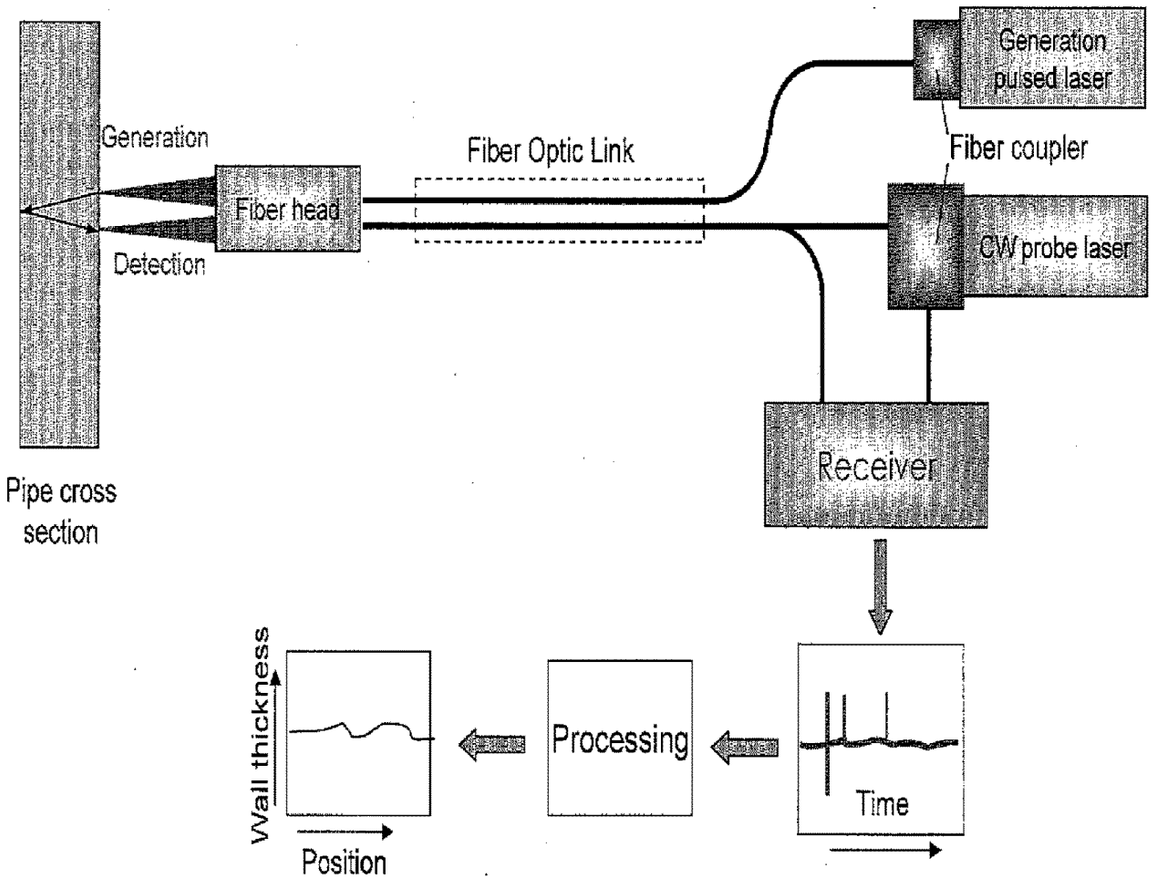
- LUT is a non-contacting method for ultrasonic non-destructive testing.
- Pulsed high-power optical laser beam is directed at the material under test.
  - Laser beam illuminates the material object, rapidly heating a thin region at the surface of the material.
  - A thermal stress is generated, launching an ultrasonic wave that propagates into the body of the material.
  - At an internal discontinuity (e.g., a void in a weld) wave is reflected, causing that surface to deform (detected by a second lower-powered laser).

Principle of LUT

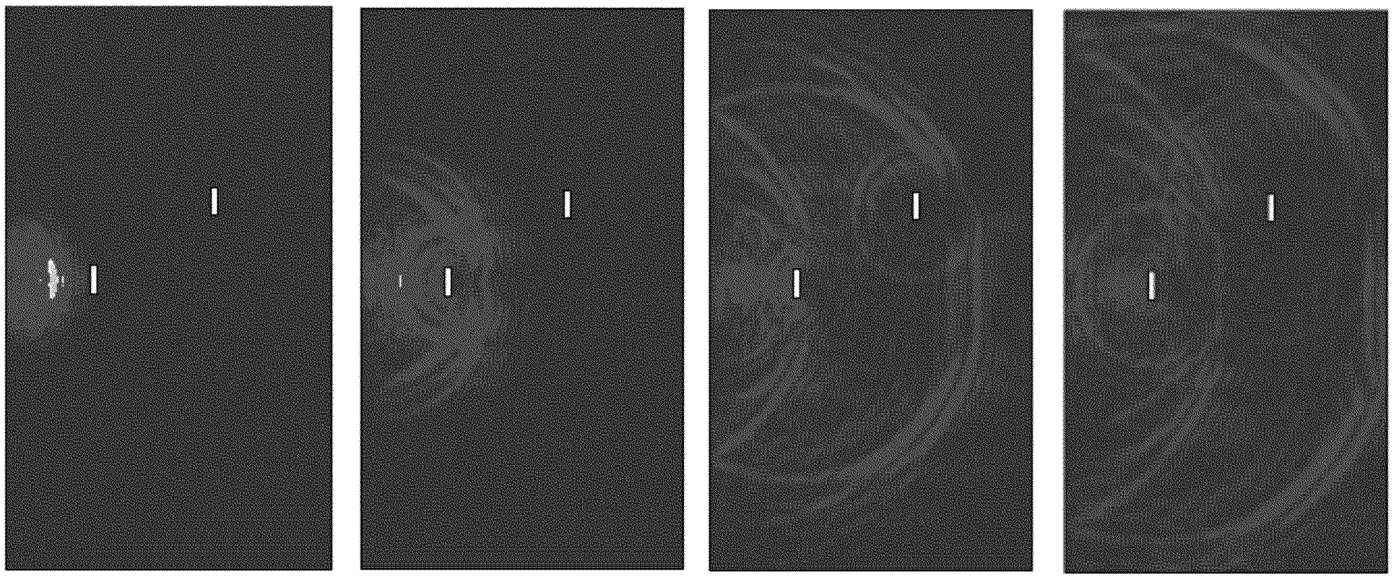


Generation and detection of picosecond strain pulses in an opaque thin film with ultrashort optical pulses. In this example the optical probe pulse arrives at the film surface at the same time as the returning strain pulse. In general, measurements are made by varying the arrival time of the optical probe pulse. Thermal expansion of the surface is omitted.

Schematic of LUT pipe inspection



LUT Modeling Results



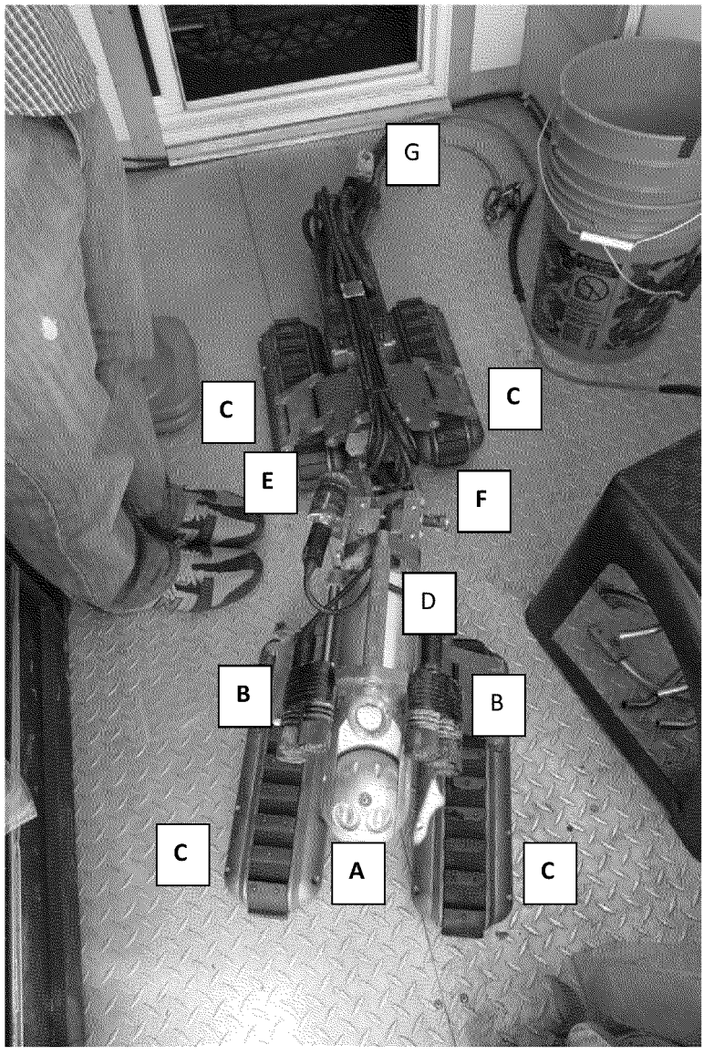
Acoustic wave generated by normal boundary acceleration.
Tint indicates local acceleration.

What can Laser Ultrasonic Testing measure?

- Dimension properties (such as thickness*) and density
- Mechanical properties such as strength, ductility, fracture toughness, magnitude of residual stresses
- Surface properties, roughness
- Presence and size of all defects and discontinuities, such as cracks, inclusions, porosity
- Quality and strength of interfaces, bonds, joints, including welds**

- *Corrosion-caused changes of the thickness of a 3/8-inch plate (typical of large-diameter natural gas pipe) could be measured by LUT to 1 or 2%
- ** Note that voids in *or substandard thickness of welds can be measured*

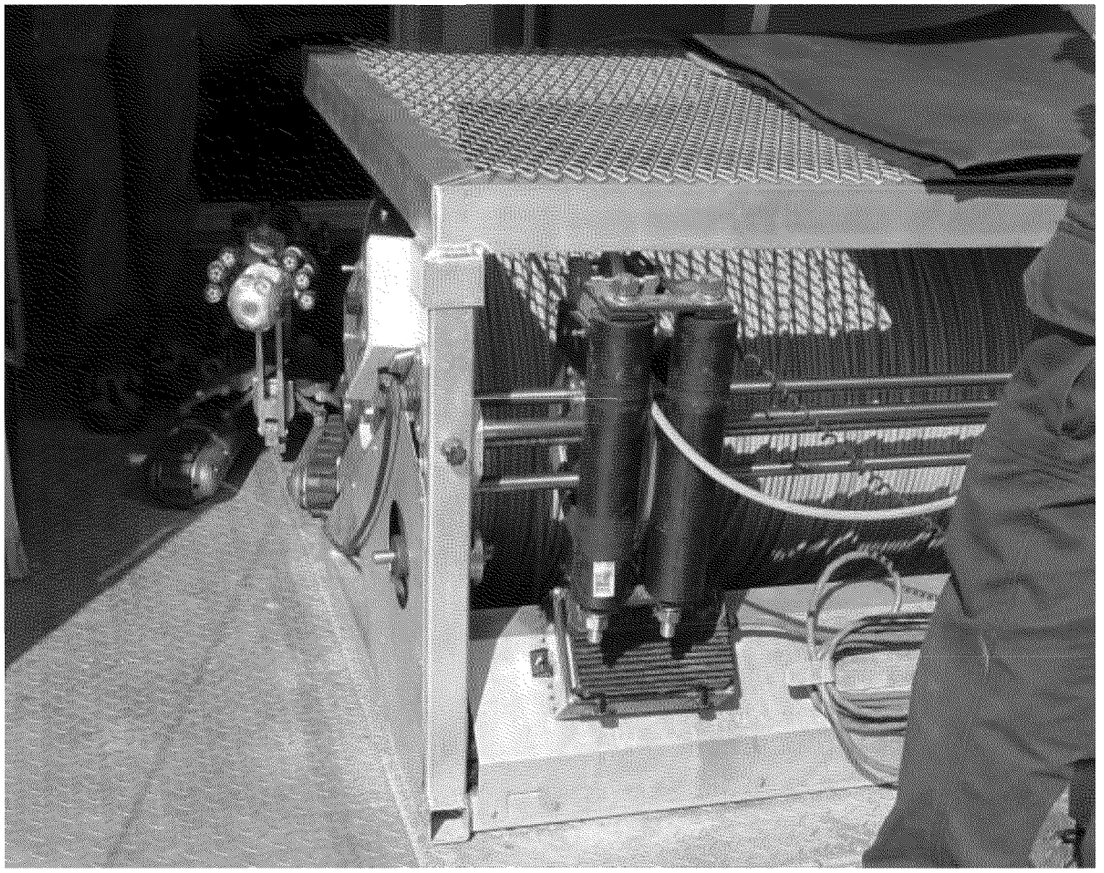
PG&E "crawler"



- A: 2 video cameras
- B: LED illuminators
- C: crawler treads
- D: electronics package
- E: light and camera to view rear tractor
- F: linkage
- G: cable (480V + optical fiber)

Head-on view of crawler

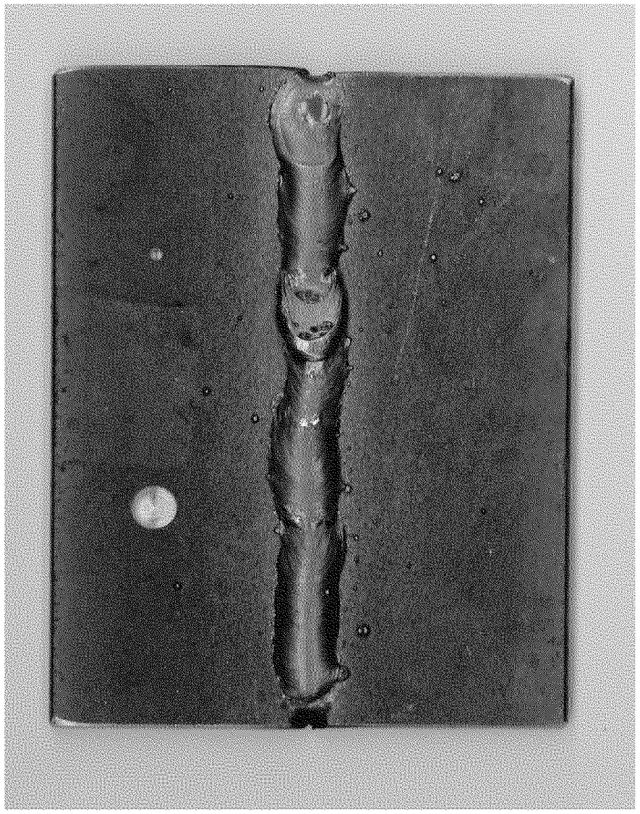
Crawler and 6500 feet of cable



Looking Forward

- Sample preparation (PG&E)
- Visit laser ultrasonic company (CA)
  - Discussion
  - Initial proof of concept
- Design for operation of LUT on crawler

LUT Sample Testing



- UCB-made sample
  - Mild steel
  - MIG welded
  - Variable shielding gas
    - (varies quality of weld)
  - Two blind holes
- PG&E offering to make samples

Sensors Status Recap

- 1st pass designs back, post-processing ongoing
- 2nd mask designs (for in-house fabrication) in progress
- Starting on the electronics
- Radio infrastructure basically ready
  - Dust Networks
- Assembling packaged prototypes w. MEMS/off-the-shelf components – through July 2012
- Laser Ultrasonic Testing
  - Collaboration with commercial companies